

## Chapter 23

# Expectation for Nuclear Transmutation

Akito Arima

**Abstract** It is my great honor and pleasure to speak to you this morning on the occasion of the International Symposium on Nuclear Back-end Issues and the Role of Nuclear Transmutation Technology after the accident of TEPCO's Fukushima Daiichi Nuclear Power Stations. I would like to thank the organizers, especially Professor Hirotake Moriyama and Professor Hajimu Yamana, for inviting me to this Symposium.

I believe that this Symposium is very important and well timed to solve urgent problems concerning nuclear back-end issues and to develop nuclear transmutation technology. I myself am a nuclear theoretical physicist and am ignorant of nuclear technology. However, I believe that nuclear energy is indispensable for the future of human beings and that nuclear engineering must be further developed.

My talk consists of the following four subjects:

1. Demand for primary energy and electricity is increasing year by year.
2. Global warming is becoming a more serious problem.
3. Development of renewable energy must be promoted. However, it will require sufficient resources of time and budget.
4. Human beings cannot avoid depending on nuclear energy as well as other energy resources that do not emit CO<sub>2</sub>.
5. Nuclear technology must be developed.
  - (a) The safety technology of nuclear energy has to be developed for the future.
  - (b) The technology for the back-end of the nuclear fuel cycle has to be enhanced. The site for final disposal of nuclear wastes has to be determined as soon as possible in Japan, which is a responsibility of the Central Government.
  - (c) The research and development of innovative technologies, such as accelerator-driven systems, must be promoted to encourage the progress of final disposal.

---

A. Arima (✉)

Japan Radioisotope Association, 2-28-45, Honkomagome, Bunkyo-ku,  
Tokyo 113-8941, Japan  
e-mail: [arima@musashi.jp](mailto:arima@musashi.jp)

- (d) Research and development of nuclear technologies for reactor decommissioning, safety technology, back-end, etc., must be promoted intensively through international cooperation.

**Keywords** Accelerator-driven system • Decommissioning • Final disposal • Nuclear back-end • Nuclear energy • Nuclear transmutation

### 23.1 Demand for Primary Energy and Electricity Is Increasing Year by Year

Figure 23.1 shows a prediction of the world population together with its past history. This figure shows that the world population had already reached 7 billion in 2011 and will be 9.2 billion in 2050. Another prediction indicates that the population of the world would be 11 billion by the end of this century.

It is not easy to predict the future demand for primary energy. Let me estimate it taking an extremely naive way. Figure 23.2 shows how much primary energy per capital is consumed annually in each country in terms of tons of oil equivalent. In 2009, the average of consumption of primary energy was 1.8 t/year and the world population was 7 billion. It is a reasonable assumption that everybody in the world hopes to enjoy the American life using 7 t/year, or at least the average of OECD countries by using 4 t/year. Let us assume that in the near future the average will become 4 t/year and the world population will be 10 billion in 2100. Then, simple arithmetic tells us that the total demand for primary energy will be 3.2 times  $[=(10 \times 4)/(7 \times 1.8)]$  more than the present consumption.

More realistically, the International Energy Agency (IEA) predicted the future demand for primary energy. The demand in countries other than OECD in 2035 will be 1.8 times more than in 2010. The demand for primary energy in the world in 2035 will be 1.35 times more than in 2010. We should be careful because this increase of 35 % will occur only 25 years from now. If this increase continues linearly for the next 100 years, we find a 140 % increase, that is, altogether 2.4 times more than the present consumption. According to IEA, the demand for electricity in the world in 2035 will be 1.73 times more than in 2011, which is an increase 2 times as fast as that for primary energy.

### 23.2 Global Warming Is Becoming a More Serious Problem

To prepare for further increase of the demand for primary energy and to stop global warming by reducing CO<sub>2</sub> emissions into the air, we need to develop renewable energy as well as nuclear energy.

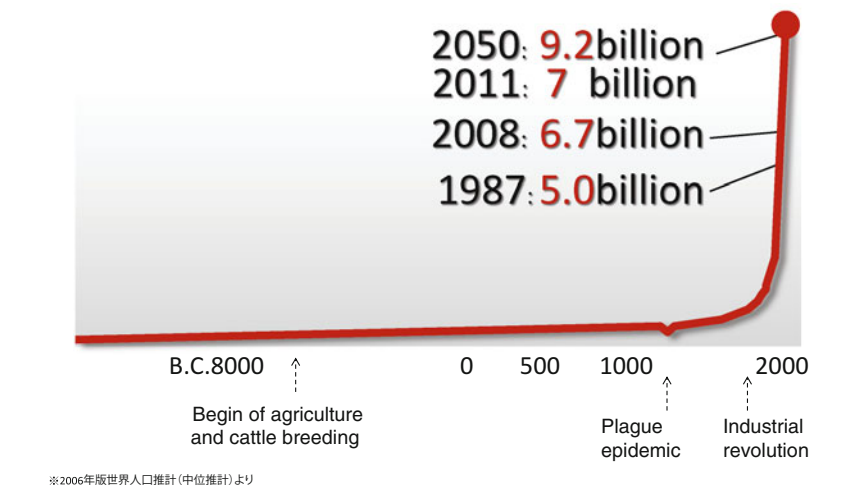


Fig. 23.1 Explosion of world population

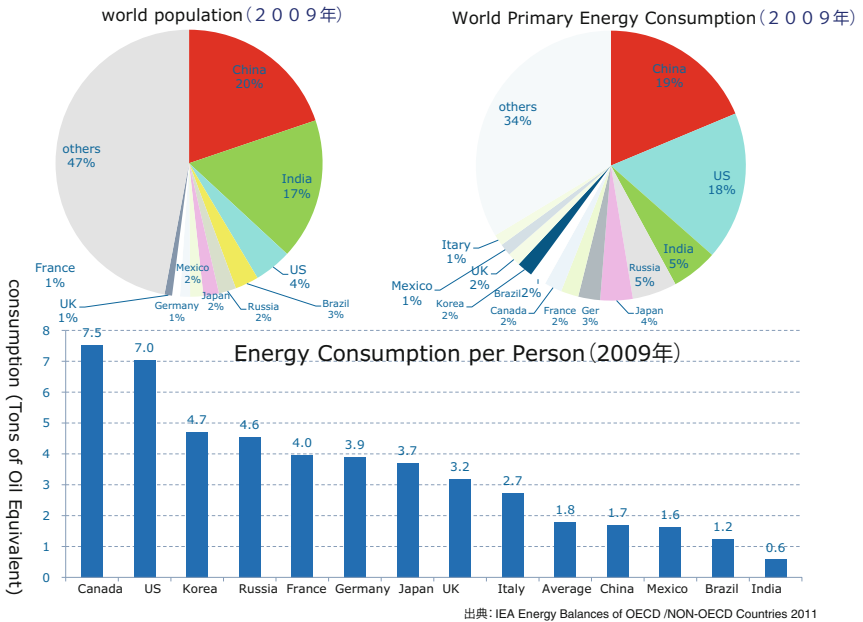


Fig. 23.2 Regional population and energy consumption per person

Warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, sea level has risen, and the concentrations of greenhouse gases have increased.

Professor Akimasa Sumi and his collaborators have carried out computer simulations using climate models for many years.

According to their results, it seems very very clear that the anthropological emission of greenhouse gases (mainly CO<sub>2</sub>) is a main contributor to global warming.

We must stop the emission of CO<sub>2</sub> to avoid global warming.

### **23.3 The Development of Renewable Energy Must Be Promoted. However, It Will Require Sufficient Resources of Time and Budget**

According to the world energy outlook of IEA, the total electric power generation will be increased as shown in Fig. 23.3. The electric power generated by renewable energy is predicted as shown in Fig. 23.4. The electric power generated by renewable energy other than water power will increase very slowly, from about 4 % in 2010 to only 15 % in 2035, whereas the electric power generated by nuclear energy will be kept almost constant from 13 % in 2010 to 12 % in 2035.

We must try to increase renewable energy more as quickly as possible.

In this respect, I commend Germany, which has strived to increase the development of renewable energy (Fig. 23.5) after 2000. In 2010, electricity generated by renewable energy reached 103.5 billion kWh. Deducting that generated by water power, we have 82.9 billion kWh. Total electric power generation in Japan was 976.2 billion kWh in 2010; that is, electric power generated by renewable energy other than water in Germany in 2010 was only 8.5 % of the total electric power generation in Japan in the same year. The electric power generated by nuclear energy in Japan was 300.4 billion kWh in 2010. Therefore, electric power generated in Germany by renewable energy sources other than water in 2010 is only 28 % of this amount. Germany has striven so much in these 10 years from 2000 to 2010, and the average price of electricity per house has doubled; that is, Germany has invested a large budget. It takes many years to increase renewable energy, and the result is still not satisfactory. Even if Japan tries as much as Germany, it will takes at least 30 years to replace nuclear energy by renewable energy. Meanwhile, Japan must depend on fossil fuel, which increases CO<sub>2</sub> emissions into the atmosphere. To import fossil fuel, the deficit in foreign trade of Japan, which is now already more than 4 trillion yen (about \$40 billion), will continue as the result of the decrease in nuclear energy.

When we stop all nuclear power stations in Japan, renewable energy must be increased, not only to replace nuclear energy but also the energy produced by fossil fuel. Is this really possible in the near future? It is time for us to deliberate upon the future of energy in Japan to guarantee energy security, to avoid global warming, and to stabilize the economy of Japan.

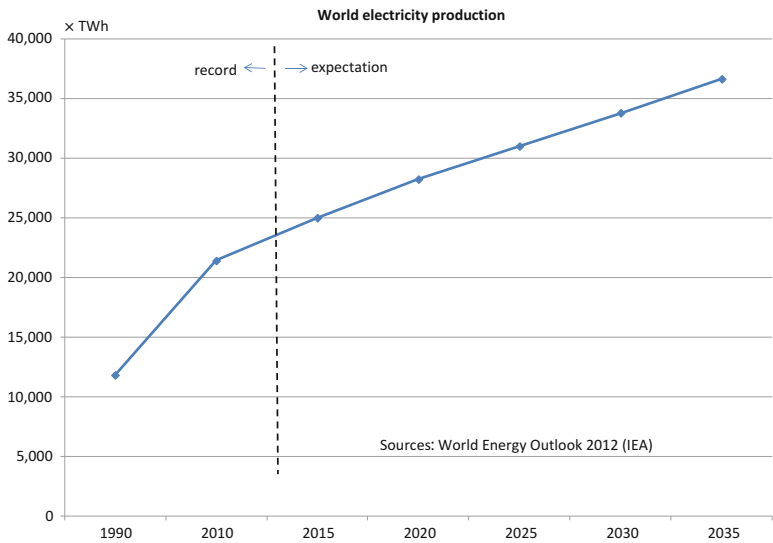


Fig. 23.3 World energy outlook of the International Energy Agency (IEA)

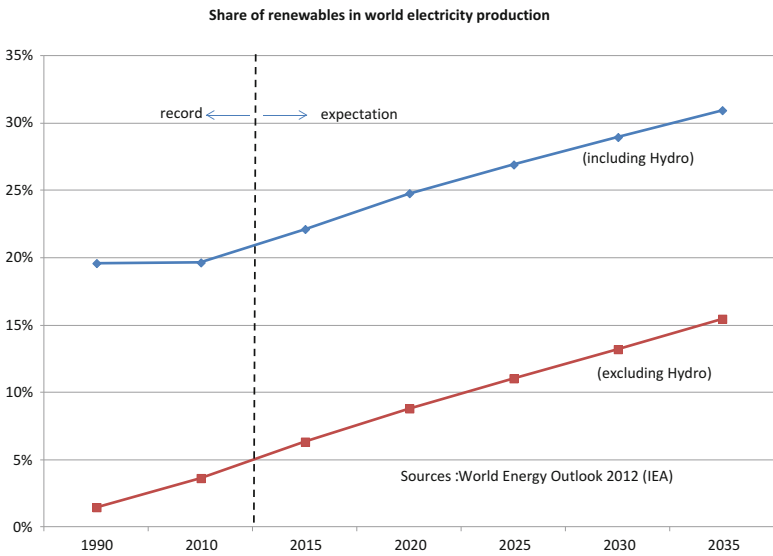


Fig. 23.4 Electric power generated by renewable energy (prediction by IEA)

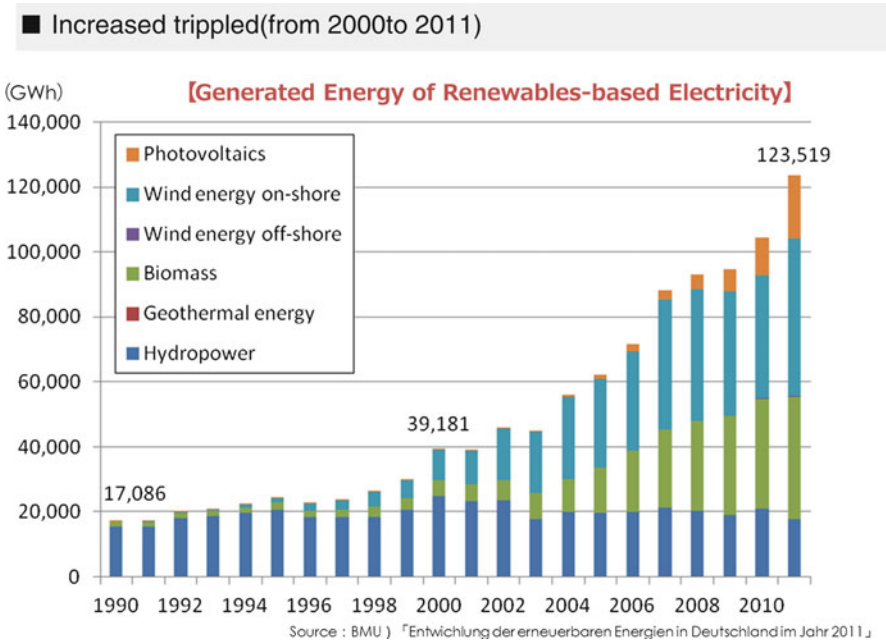


Fig. 23.5 Development of renewables-based electricity generation in Germany

## 23.4 Human Beings Cannot Avoid Depending on Nuclear Energy as Well as Other Energy Resources, Including Renewable Energy, Which Do Not Emit CO<sub>2</sub> into the Air

It is now very clear that it is almost impossible for renewable energy to replace fossil fuel in the near future. Both nuclear energy and renewable energy are necessary, not only in Japan but also in the world. At the same time we must develop a new technology to compensate for CO<sub>2</sub> emissions from fossil fuels.

## 23.5 Nuclear Technology Must be Developed

### 23.5.1 Safety Technology of Nuclear Energy Must Be Developed for the Future

Concerning nuclear energy, we must not stop researching and developing new advanced reactors in which greater safety is guaranteed against natural calamities as well as manmade disaster. Small-scale nuclear reactors also should be developed

to decentralize electric power stations. If economical problems are overcome, smaller-scale reactors might be easier to guarantee safety.

***23.5.2 Technology for the Back-end of the Nuclear Fuel Cycle Must Be Enhanced. The Site for Final Disposal of Nuclear Wastes Must be Determined as Soon as Possible in Japan, Which is a Responsibility of the Central Government***

I have learned that technology for the back-end of the nuclear fuel cycle has already been well developed, but it still does not seem to be working well.

I hope that the solutions will be realized as soon as possible. Especially, the location for final disposal of nuclear wastes must be determined as soon as possible, and this is really a responsibility of the National Government to determine the location for the final disposal.

Not only Japan, but almost all countries including Germany, USA, Britain, and Russia, have not yet decided the location for final disposal, excepting Finland and Sweden. This decision must be made irrespective of whether nuclear power stations are to be continued.

***23.5.3 Research and Development of Innovative Technologies, Such as Accelerator-Driven Systems, Must Be Promoted to Encourage the Progress of Final Disposal***

It is extremely important to shorten the lifetimes of many radioactive nuclei in nuclear wastes. The role of nuclear transmutation technology is one of the main themes of this Symposium. The accelerator-driven system is one of the most promising methods to transmute radioactive nuclei to those of shorter lifetimes.

In Japan, the Omega project, which includes an accelerator-driven system, has been discussed for more than 10 years. I have helped to establish the J-PARC because one of its purposes is to develop the transmutation technology.

I expect that Dr. Hiroyuki Oigawa will tell us about the accelerator-driven system.

I would like to learn about the present situation of the transmutation technology in Japan and in the world.

### ***23.5.4 The Research and Development of Nuclear Technologies for Reactor Decommissioning, Safety Technology, Back-end, etc., Must Be Promoted Intensively Through International Cooperation***

Nuclear technologies for reactor decommissioning, safety technology, back-end, etc., must be urgently developed. They are very important, especially in Japan after the Fukushima Daiichi Accident.

These technologies, however, are also desired in all countries that already have nuclear power stations, and also in countries which are planning nuclear power stations. These technologies therefore should be researched and developed through international cooperation. Fukushima would be a very good candidate for us to construct an international center for researching and developing technologies for reactor decommissioning.

## **23.6 Conclusion**

For the future of human beings, nuclear technology is indispensable to guarantee the safety of energy and to reduce CO<sub>2</sub> in the atmosphere, which causes global warming.

For promoting nuclear technology, we must encourage young researchers to be interested in nuclear science and engineering. Education is very important for this purpose.

You who are experts in nuclear science and technology should be very proud of your specialty. It is the most important time for you to solve very difficult problems after the accident of the Fukushima Daiichi Nuclear Power Station. I sincerely hope that you will overcome this crisis caused by the Fukushima accident.

Let us change the misfortune into good luck for the future of human beings.

I hope that this Symposium will succeed in producing good fruits.

**Open Access** This chapter is distributed under the terms of the Creative Commons Attribution Noncommercial License, which permits any noncommercial use, distribution, and reproduction in any medium, provided the original author(s) and source are credited.